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D. Tsiang
G. Suwala
Cisco Systems
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The Cisco SRP MAC Layer Protocol

Status of this Memo

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Abstract

This document specifies the MAC layer protocol, "Spatial Reuse Protocol" (SRP) for use with ring based media. This is a second version of the protocol (V2).

The primary requirements for SRP are as follows:

- Efficient use of bandwidth using:
  spatial reuse of bandwidth
  local reuse of bandwidth
  minimal protocol overhead
- Support for priority traffic
- Scalability across a large number of nodes or stations attached to a ring
- "Plug and play" design without a software based station management transfer (SMT) protocol or ring master negotiation as seen in other ring based MAC protocols [1][2]
- Fairness among nodes using the ring
- Support for ring based redundancy (error detection, ring wrap, etc.) similar to that found in SONET BLSR specifications.
- Independence of physical layer (layer 1) media type.

This document defines the terminology used with SRP, packet formats, the protocol format, protocol operation and associated protocol finite state machines.

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1. Differences between SRP V1 and V2

This document pertains to SRP V2. SRP V1 was a previously published draft specification. The following lists V2 feature differences from V1:

- Reduction of the header format from 4 bytes to 2 bytes.

- Replacement of the keepalive packet with a new control packet that carries usage information in addition to providing a keepalive function.

- Change bit value of inner ring to be 1 and outer to be 0.

- Reduction in the number of TTL bits from 11 to 8.

- Removal of the DS bit.

- Change ordering of CRC transmission to be most significant octet first (was least significant octet in V1). The SRP CRC is now the same as in [5].

- Addition of the SRP cell mode to carry ATM cells over SRP.

- Changes to the SRP-fa to increase the usage field width and to remove the necessity of adding a fixed constant when propagating usage messages.

2. Terms and Taxonomy

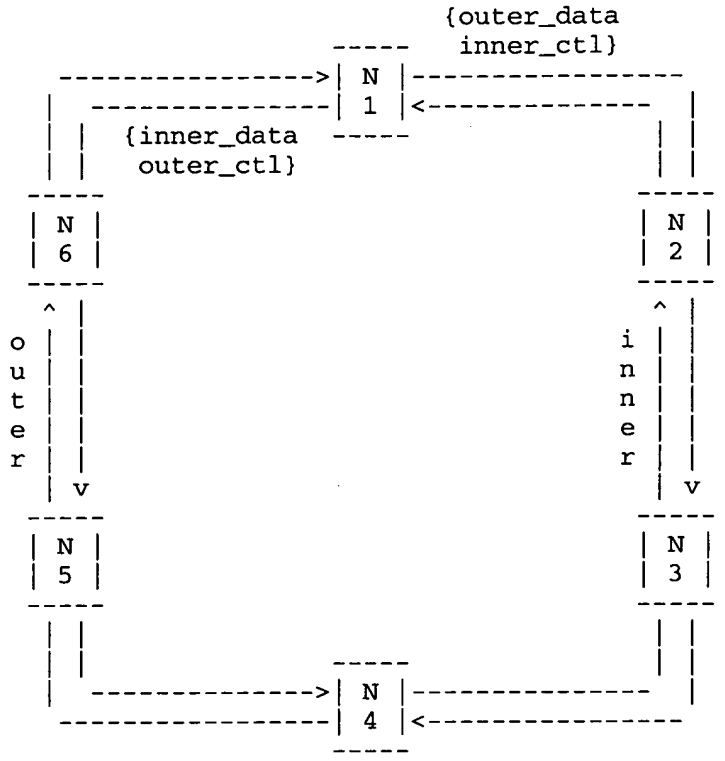
2.1. Ring Terminology

SRP uses a bidirectional ring. This can be seen as two symmetric counter-rotating rings. Most of the protocol finite state machines (FSMs) are duplicated for the two rings.

The bidirectional ring allows for ring-wrapping in case of media or station failure, as in FDDI [1] or SONET/SDH [3]. The wrapping is controlled by the Intelligent Protection Switching (IPS) protocol.

To distinguish between the two rings, one is referred to as the "inner" ring, the other the "outer" ring. The SRP protocol operates by sending data traffic in one direction (known as "downstream") and it's corresponding control information in the opposite direction (known as "upstream") on the opposite ring. Figure 1 highlights this graphically.

FIGURE 1. Ring Terminology



2.2. Spatial Reuse

Spatial Reuse is a concept used in rings to increase the overall aggregate bandwidth of the ring. This is possible because unicast traffic is only passed along ring spans between source and destination nodes rather than the whole ring as in earlier ring based protocols such as token ring and FDDI.

Figure 2 below outlines how spatial reuse works. In this example, node 1 is sending traffic to node 4, node 2 to node 3 and node 5 to node 6. Having the destination node strip unicast data from the ring allows other nodes on the ring who are downstream to have full access to the ring bandwidth. In the example given this means node 5 has full bandwidth access to node 6 while other traffic is being simultaneously transmitted on other parts of the ring.

2.3. Fairness

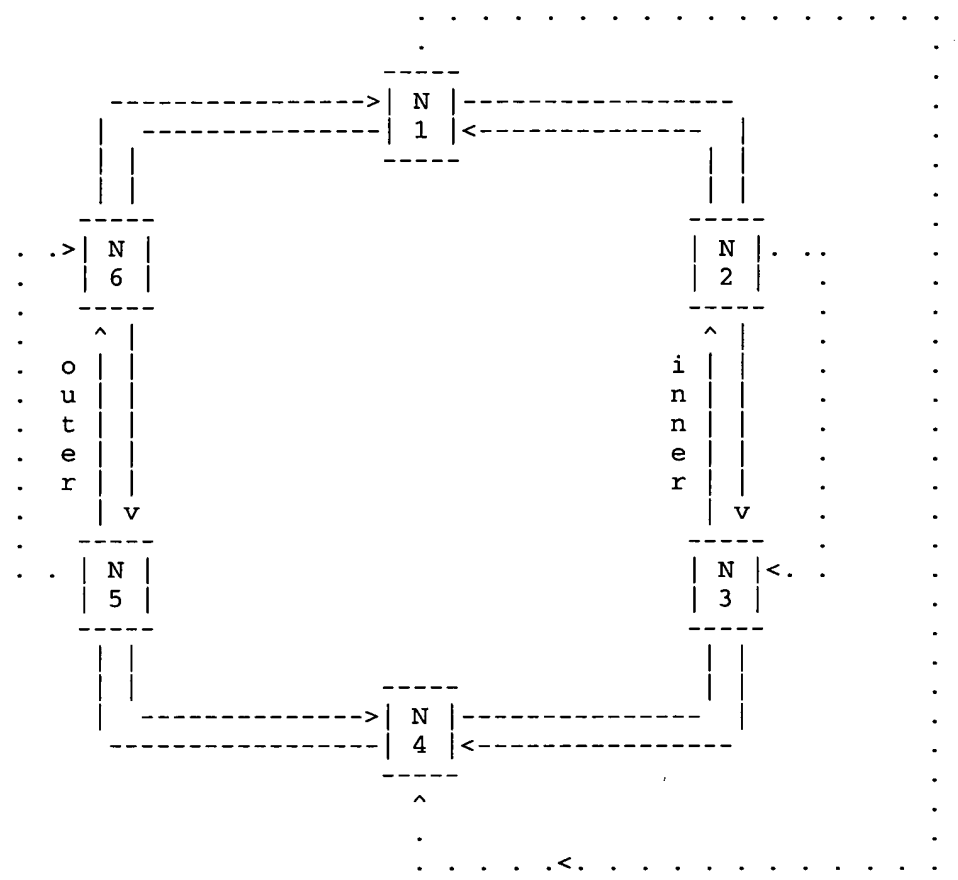
Since the ring is a shared media, some sort of access control is necessary to ensure fairness and to bound latency. Access control can be broken into two types which can operate in tandem:

Global access control - controls access so that everyone gets a fair share of the global bandwidth of the ring.

Local access control - grants additional access beyond that allocated globally to take advantage of segments of the ring that are less than fully utilized.

As an example of a case where both global and local access are required, refer again to Figure 2. Nodes 1, 2, and 5 will get 1/2 of the bandwidth on a global allocation basis. But from a local perspective, node 5 should be able to get all of the bandwidth since its bandwidth does not interfere with the fair shares of nodes 1 and 2.

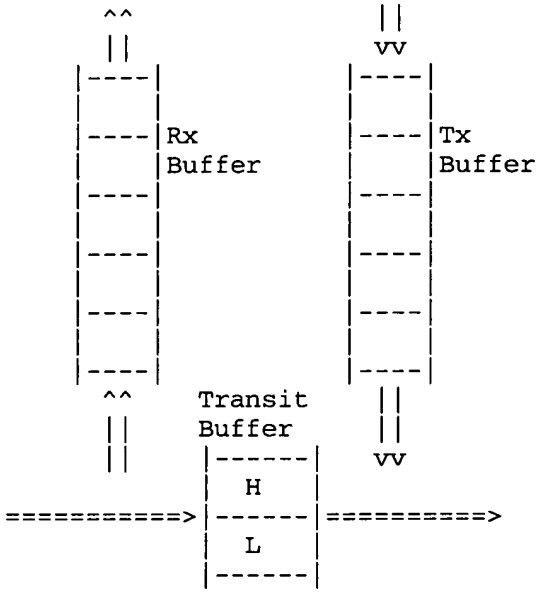
FIGURE 2. Global and Local Re-Use



2.4. Transit Buffer

To be able to detect when to transmit and receive packets from the ring, SRP makes use of a transit (sometimes referred as insertion) buffer as shown in Figure 3 below. High priority packets and low priority packets can be placed into separate fifo queues.

FIGURE 3. Transit buffer



3. SRP Overview

3.1. Receive Operation Overview

Receive Packets entering a node are copied to the receive buffer if a Destination Address (DA) match is made. If a DA matched packet is also a unicast, then the packet will be stripped. If a packet does not DA match or is a multicast and the packet does not Source Address (SA) match, then the packet is placed into the Transit Buffer (TB) for forwarding to the next node if the packet passes Time To Live and Cyclic Redundancy Check (CRC) tests.

3.2. Transmit Operation Overview

Data sent from the node is either forwarded data from the TB or transmit data originating from the node via the Tx Buffer. High priority forwarded data always gets sent first. High priority transmit data may be sent as long as the Low Priority Transit Buffer (LPTB) is not full.

A set of usage counters monitor the rate at which low priority transmit data and forwarded data are sent. Low priority data may be sent as long as the usage counter does not exceed an allowed usage governed by the SRP-fa rules and the LPTB has not exceeded the low priority threshold.

3.3. SRP Fairness Algorithm (SRP-fa) Overview

If a node experiences congestion, then it will advertise to upstream nodes via the opposite ring the value of its transmit usage counter. The usage counter is run through a low pass filter function to stabilize the feedback. Upstream nodes will adjust their transmit rates so as not to exceed the advertised values. Nodes also propagate the advertised value received to their immediate upstream neighbor. Nodes receiving advertised values who are also congested propagate the minimum of their transmit usage and the advertised usage.

Congestion is detected when the depth of the low priority transit buffer reaches a congestion threshold.

Usage messages are generated periodically and also act as keepalives informing the upstream station that a valid data link exists.

3.4. Intelligent Protection Switching (IPS) Protocol Overview

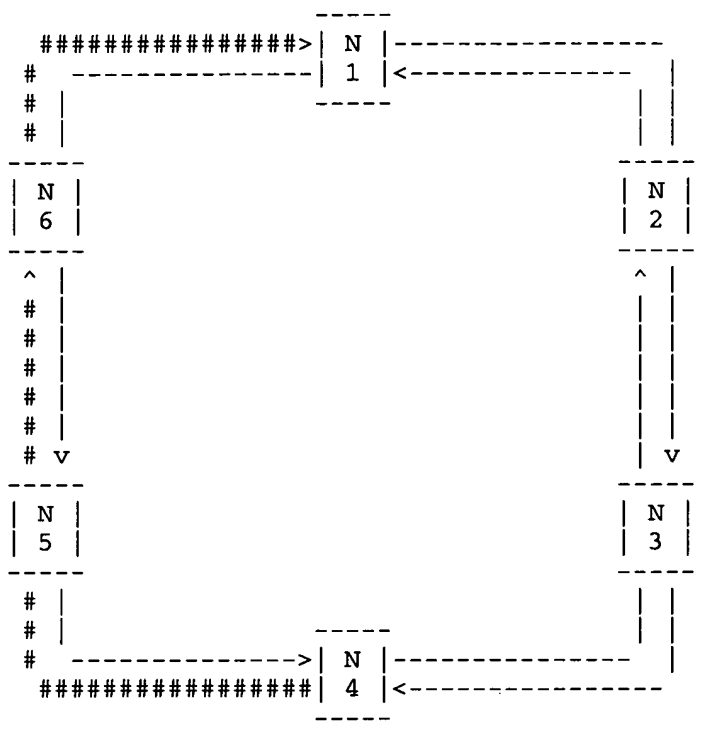
An SRP Ring is composed of two counter-rotating, single fiber rings. If an equipment or fiber facility failure is detected, traffic going towards and from the failure direction is wrapped (looped) back to go in the opposite direction on the other ring (subject to the protection hierarchy). The wrap around takes place on the nodes adjacent to the failure, under control of the IPS protocol. The wrap re-routes the traffic away from the failed span.

An example of the data paths taken before and after a wrap are shown in Figures 4 and 5. Before the fiber cut, N4 sends to N1 via the path N4->N5->N6->N1.

If there is a fiber cut between N5 and N6, N5 and N6 will wrap the inner ring to the outer ring. After the wraps have been set up, traffic from N4 to N1 initially goes through the non-optimal path N4->N5->N4->N3->N2->N1->N6->N1.

Subsequently a new ring topology is discovered and a new optimal path is used N4->N3->N2-N1 as shown in Figure 6. Note that the topology discovery and the subsequent optimal path selection are not part of the IPS protocol.

FIGURE 4. Data path before wrap, N4 -> N1



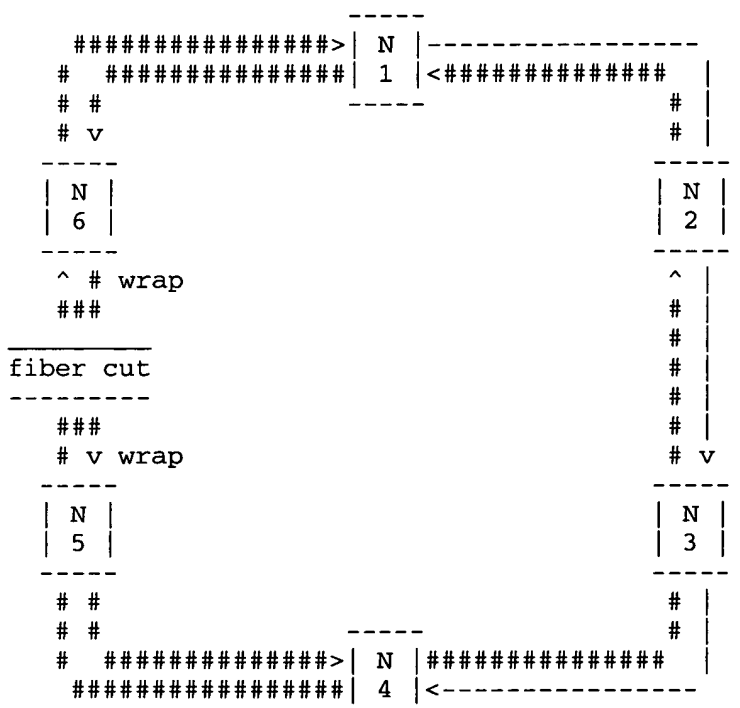
The ring wrap is controlled through SONET BLSR [3][4] style IPS signaling. It is an objective to perform the wrapping as fast as in the SONET equipment or faster.

The IPS protocol processes the following request types (in the order of priority, from highest to lowest):

1. Forced Switch (FS): operator originated, performs a protection switch on a requested span (wraps at both ends of the span)

2. Signal Fail (SF): automatic, caused by a media Signal Failure or SRP keep-alive failure - performs a protection switch on a requested span

FIGURE 5. Data path after the wrap, N4 -> N1



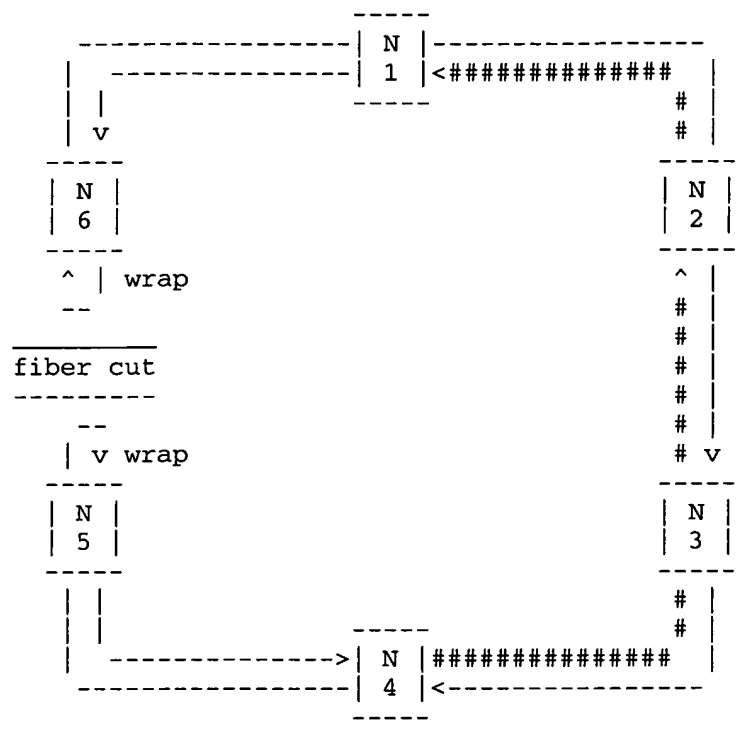
3. Signal Degrade (SD): automatic, caused by a media Signal Degrade (e.g. excessive Bit Error Rate) - performs a protection switch on a requested span

4. Manual Switch (MS): operator originated, like Forced Switched but of a lower priority

5. Wait to Restore (WTR): automatic, entered after the working channel meets the restoration criteria after SF or SD condition disappears. IPS waits WTR period before restoring traffic in order to prevent protection switch oscillations

If a protection (either automatic or operator originated) is requested for a given span, the node on which the protection has been requested issues a protection request to the node on the other end of the span using both the short path (over the failed span, as the failure may be unidirectional) and the long path (around the ring).

FIGURE 6. Data path after the new topology is discovered



As the protection requests travel around the ring, the protection hierarchy is applied. If the requested protection switch is of the highest priority e.g. Signal Fail request is of higher priority than the Signal Degrade than this protection switch takes place and the lower priority switches elsewhere in the ring are taken down, as appropriate. If a lower priority request is requested, it is not allowed if a higher priority request is present in the ring. The only exception is multiple SF and FS switches, which can coexist in the ring.

All protection switches are performed bidirectionally (wraps at both ends of a span for both transmit and receive directions, even if a failure is only unidirectional).

4. Packet Formats

This section describes the packet formats used by SRP. Packets can be sent over any point to point link layer (e.g. SONET/SDH, ATM, point to point ETHERNET connections). The maximum transfer unit (MTU) is 9216 octets. The minimum transfer unit for data packets is 55 octets. The maximum limit was designed to accommodate the large IP MTUs of IP over AAL5. SRP also supports ATM cells. ATM cells over SRP are 55 octets. The minimum limit corresponds to ATM cells transported over SRP. The minimum limit does not apply to control packets which may be smaller.

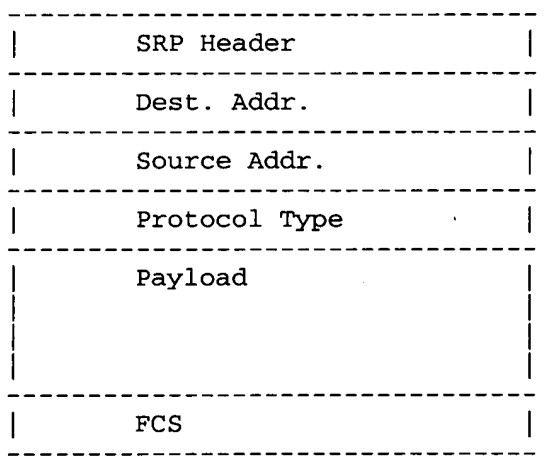
These limits include everything listed in Figure 7: but are exclusive of the frame delineation (e.g. for SRP over SONET/SDH, the flags used for frame delineation are not included in the size limits).

The following packet and cell formats do not include any layer 1 frame delineation. For SRP over POS, there will be an additional flag that delineates start and end of frame.

4.1. Overall Packet Format

The overall packet format is show below in Figure 7:

FIGURE 7. Overall Packet Format



The frame check sequence (FCS) is a 32-bit cyclic redundancy check (CRC) as specified in RFC-1662 and is the same CRC as used in Packet Over SONET (POS - specified in RFC-2615). The generator polynomial is:

CRC-32:

x32 + x26 + x23 + x22 + x16 + x12 + x11 + x10 + x8 + x7 + x5 + x4 + x2 + x + 1

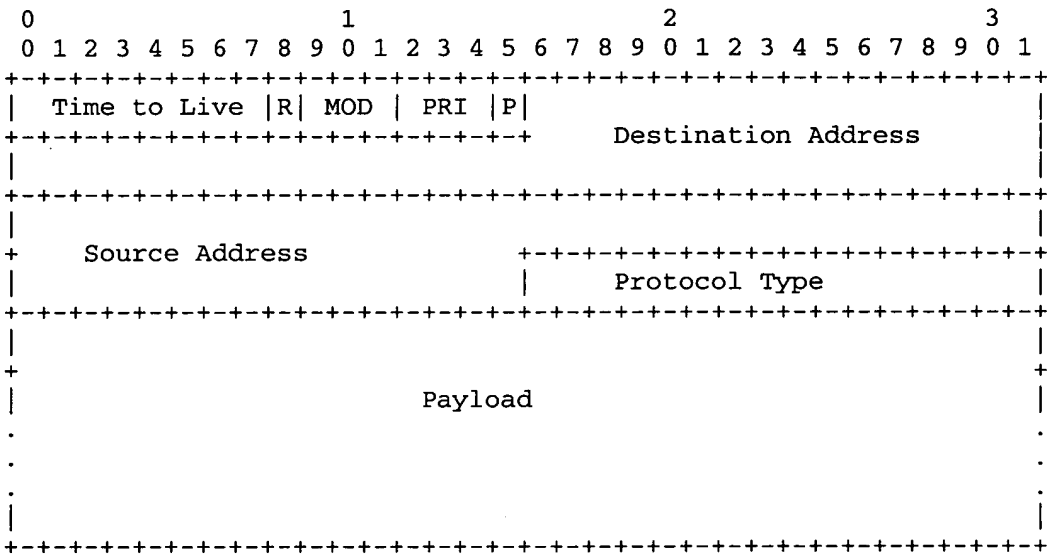
The FCS is computed over the destination address, source address, protocol type and payload. It does not include the SRP header.

Note that the packet format after the SRP header is identical to Ethernet Version 2.

4.2. Generic Packet Header Format

Each packet has a fixed-sized header. The packet header format is shown in Figure 8.

FIGURE 8. Detailed Packet Header Format



The fields are described below.

4.2.1. Time To Live (TTL)

This 8 bit field is a hop-count that must be decremented every time a node forwards a packet. If the TTL reaches zero it is stripped off the ring. This allows for a total node space of 256 nodes on a ring. However, due to certain failure conditions (e.g. when the ring is

wrapped) the total number of nodes that are supported by SRP is 128. When a packet is first sent onto the ring the TTL should be set to at least twice the total number of nodes on the ring.

4.2.2. Ring Identifier (R)

This single bit field is used to identify which ring this packet is designated for. The designation is as follows:

TABLE 1. Ring Indicator Values

Outer Ring	0
Inner Ring	1

4.2.3. Priority Field (PRI)

This three bit field indicates the priority level of the SRP packet (0 through 7). The higher the value the higher the priority. Since there are only two queues in the transit buffer (HPTB and LPTB) a packet is treated as either low or high priority once it is on the ring. Each node determines the threshold value for determining what is considered a high priority packet and what is considered a low priority packet. However, the full 8 levels of priority in the SRP header can be used prior to transmission onto the ring (transmit queues) as well as after reception from the ring (receive queues).

4.2.4. MODE

This three bit field is used to identify the mode of the packet. The following modes are defined in Table 2 below.

TABLE 2. MODE Values

Value	Description
000	Reserved
001	Reserved
010	Reserved
011	ATM cell
100	Control Message (Pass to host)
101	Control Message (Locally Buffered for host)
110	Usage Message
111	Packet Data

These modes will be further explained in later sections.

4.2.5. Parity Bit (P-bit)

The parity bit is used to indicate the parity value over the 15 bits of the SRP header to provide additional data integrity over the header. Odd parity is used (i.e. the number of ones including the parity bit shall be an odd number).

4.2.6. Destination Address

The destination address is a globally unique 48 bit address assigned by the IEEE.

4.2.7. Source Address

The source address is a globally unique 48 bit address assigned by the IEEE.

4.2.8. Protocol Type

The protocol type is a two octet field like that used in EtherType representation. Current defined values relevant to SRP are defined in Table 3 below.

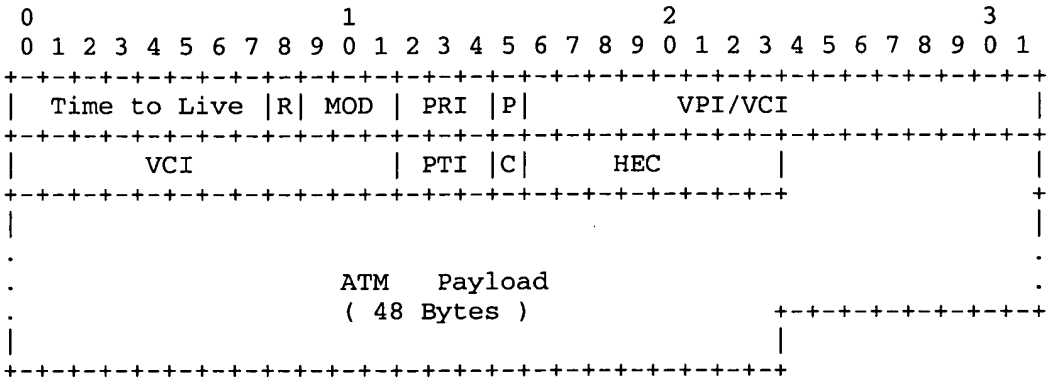
TABLE 3. Defined Protocol Types

Value	Protocol Type
0x2007	SRP Control
0x0800	IP version 4
0x0806	ARP

4.3. SRP Cell Format

SRP also supports the sending of ATM cells. The detailed cell format is shown below:

FIGURE 9. SRP Cell Format



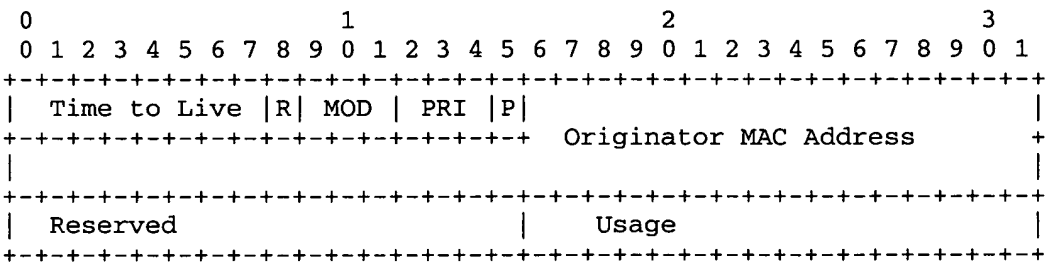
Packet nodes would typically ignore (never receive or strip) and always forward ATM-cells. The idea is that ATM switches and routers could coexist in a ring. Note that SRP cells do not contain an FCS. Data integrity is handled at the AAL layer.

4.4. SRP Usage Packet Format

SRP usage packets are sent out periodically to propagate allowed usage information to upstream nodes. SRP usage packets also perform a keepalive function. SRP usage packets should be sent approximately every 106 usec.

If a receive interface has not seen a usage packet within the keepalive timeout interval it will trigger an L2 keepalive timeout interrupt/event. The IPS software will subsequently mark that interface as faulty and initiate a protection switch around that interface. The keepalive timeout interval should be set to 16 times the SRP usage packet transmission interval.

FIGURE 10. Usage Packet Format



A USAGE of all ones indicates a value of NULL.

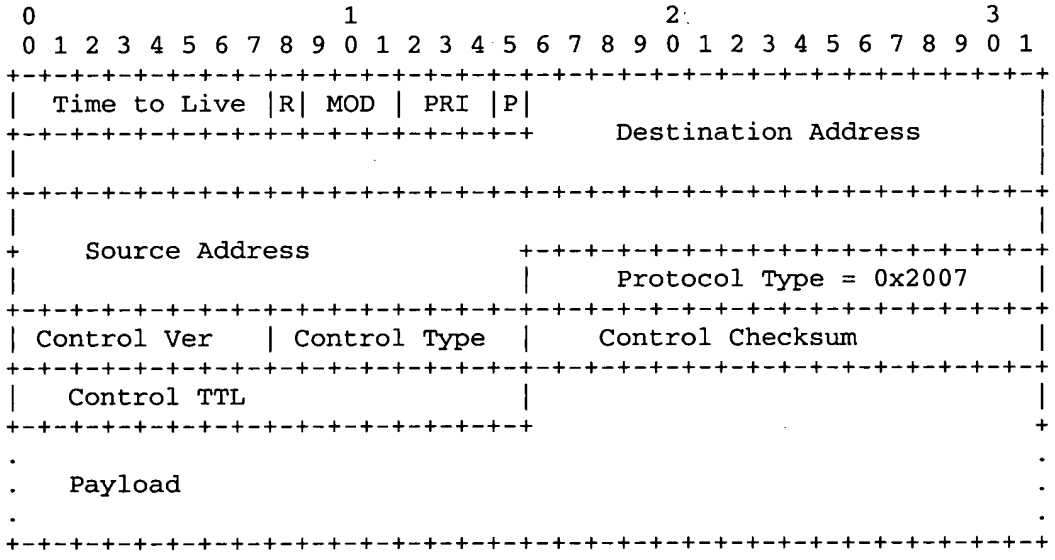
4.5. SRP Control Packet Format

If the MODE bits are set to 10X (SRP control) then this indicates a control message. Control messages are always received and stripped by the adjacent node. They are by definition unicast, and do not need any addressing information. The destination address field for control packets should be set to 0's. The source address field for a control packet should be set to the source address of the transmitting node.

Two types of controls messages are defined : Pass to host and Locally buffered. Pass to host messages can be passed to the host software by whatever means is convenient. This is most often the same path used to transfer data packets to the host. Locally buffered control messages are usually reserved for protection messages. These are normally buffered locally in order to not contend for resources with data packets. The actual method of handling these messages is up to the implementor.

The control packet format is shown in Figure 11.

FIGURE 11. Control Packet Format



The priority (PRI) value should be set to 0x7 (all one's) when sending control packets and should be queued to the highest priority transmit queue available. The Time to Live is not relevant since all

packets will be received and stripped by the nearest downstream neighbor and can be set to any value (preferably this should be set to 001).

4.5.1. Control Ver

This one octet field is the version number associated with the control type field. Initially, all control types will be version 0.

4.5.2. Control Type

This one octet field represents the control message type. Table 4 contains the currently defined control types.

TABLE 4. Control Types

Control Type	Description
0x01	Topology Discovery
0x02	IPS message
0x03-0xFF	Reserved

4.5.3. Control TTL

The Control TTL is a control layer hop-count that must be decremented every time a node forwards a control packet. If a node receives a control packet with a control TTL <= 1, then it should accept the packet but not forward it.

Note that the control layer hop count is separate from the SRP L2 TTL which is always set to 1 for control messages.

The originator of the control message should set the initial value of the control TTL to the SRP L2 TTL normally used for data packets.

4.5.4. Control Checksum

The checksum field is the 16 bit one's complement of the one's complement sum of all 16 bit words starting with the control version. If there are an odd number of octets to be checksummed, the last octet is padded on the right with zeros to form a 16 bit word for checksum purposes. The pad is not transmitted as part of the segment. While computing the checksum, the checksum field itself is replaced with zeros. This is the same checksum algorithm as that used for TCP. The checksum does not cover the 32 bit SRP FCS.

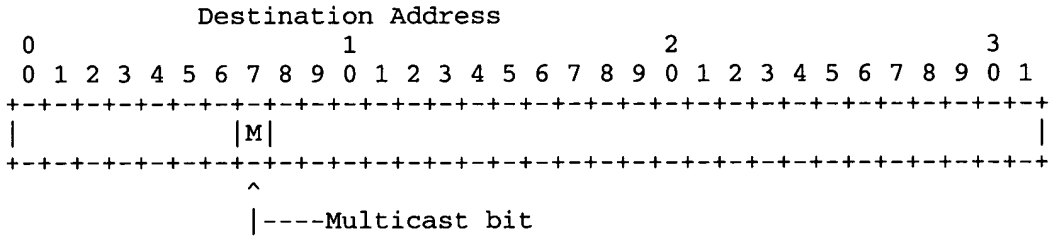
4.5.5. Payload

The payload is a variable length field dependent on the control type.

4.5.6. Addressing

All nodes must have a globally unique IEEE 48 bit MAC address. A multicast bit is defined using canonical addressing conventions i.e. the multicast bit is the least significant bit of the most significant octet in the destination address. It is acceptable but not advisable to change a node's MAC address to one that is known to be unique within the administrative layer 2 domain (that is the SRP ring itself along with any networks connected to the SRP ring via a layer 2 transparent bridge).

FIGURE 12. Multicast bit position



Note that for SONET media, the network order is MSB of each octet first, so that as viewed on the line, the multicast bit will be the 8th bit of the destination address sent. (For SRP on Ethernet media, the multicast bit would be sent first).

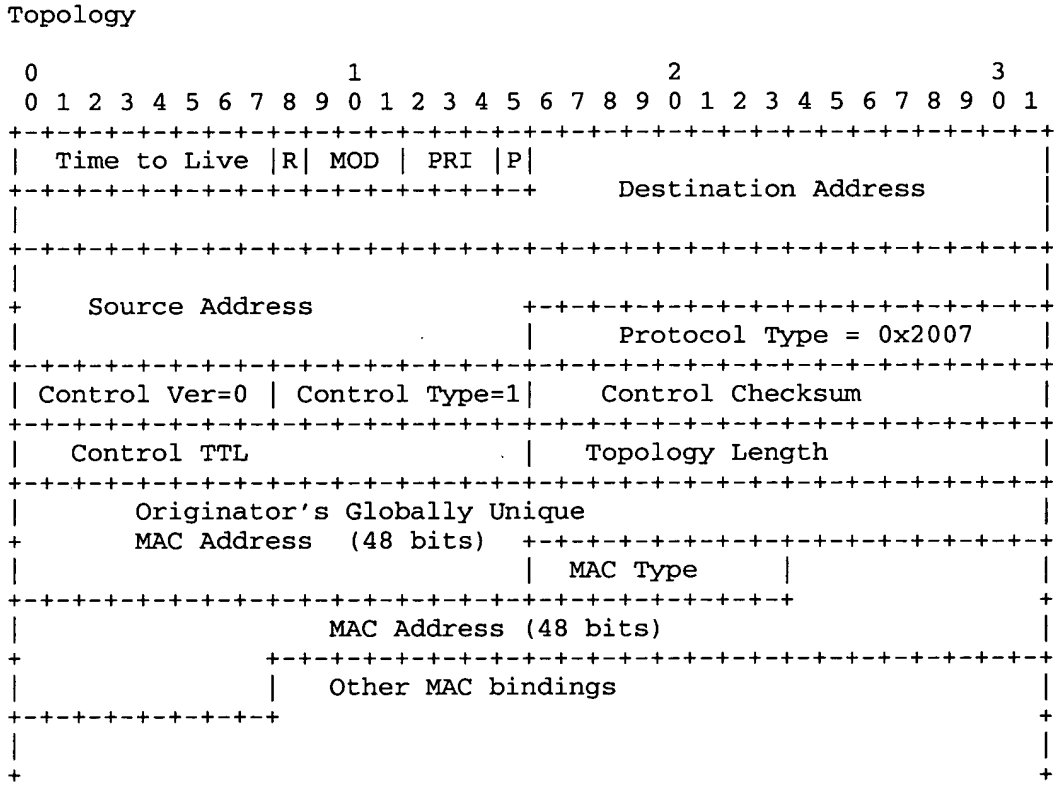
4.6. Topology Discovery

Each node performs topology discovery by sending out topology discovery packets on one or both rings. The node originating a topology packet marks the packet with the egressing ring id, appends the node's mac binding to the packet and sets the length field in the packet before sending out the packet. This packet is a point-to-point packet which hops around the ring from node to node. Each node appends its mac address binding, updates the length field and sends it to the next hop on the ring. If there is a wrap on the ring, the wrapped node will indicate a wrap when appending its mac binding and wrap the packet. When the topology packets travel on the wrapped section with the ring identifier being different from that of the topology packet itself, the mac address bindings are not added to the packet.

Eventually the node that generated the topology discovery packet gets back the packet. The node makes sure that the packet has the same ingress and egress ring id before excepting the packet. A topology map is changed only after receiving two topology packets which indicate the same new topology (to prevent topology changes on transient conditions).

Note that the topology map only contains the reachable nodes. It does not correspond to the failure-free ring in case of wraps and ring segmentations.

FIGURE 13. Topology Packet Format



Note that the Source address should be set to the source address of the TRANSMITTING node (which is not necessarily the ORIGINATING node).

4.6.1. Topology Length

This two octet field represents the length of the topology message in octets starting with the first MAC Type/MAC Address binding.

4.6.2. Topology Originator

A topology discovery packet is determined to have been originated by a node if the originator's globally unique MAC address of the packet is that node's globally unique MAC address (assigned by the IEEE).

Because the mac addresses could be changed at a node, the IEEE MAC address ensures that a unique identifier is used to determine that the topology packet has gone around the ring and is to be consumed.

4.6.3. MAC bindings

Each MAC binding shall consist of a MAC Type field followed by the node's 48 bit MAC address. The first MAC binding shall be the MAC binding of the originator. Usually the originator's MAC address will be it's globally unique MAC Address but some implementations may allow this value to be overridden by the network administrator.

4.6.4. MAC Type Format

This 8 bit field is encoded as follows:

TABLE 5. MAC Type Format

Bit	Value
0	Reserved
1	Ring ID (1 or 0)
2	Wrapped Node (1) / Unwrapped Node (0)
3-7	Reserved

Determination of whether a packet's egress and ingress ring ID's are a match should be done by using the Ring ID found in the MAC Type field of the last MAC binding as the ingress ring ID rather than the R bit found in the SRP header. Although they should be the same, it is better to separate the two functions as some implementations may not provide the SRP header to upper layer protocols.

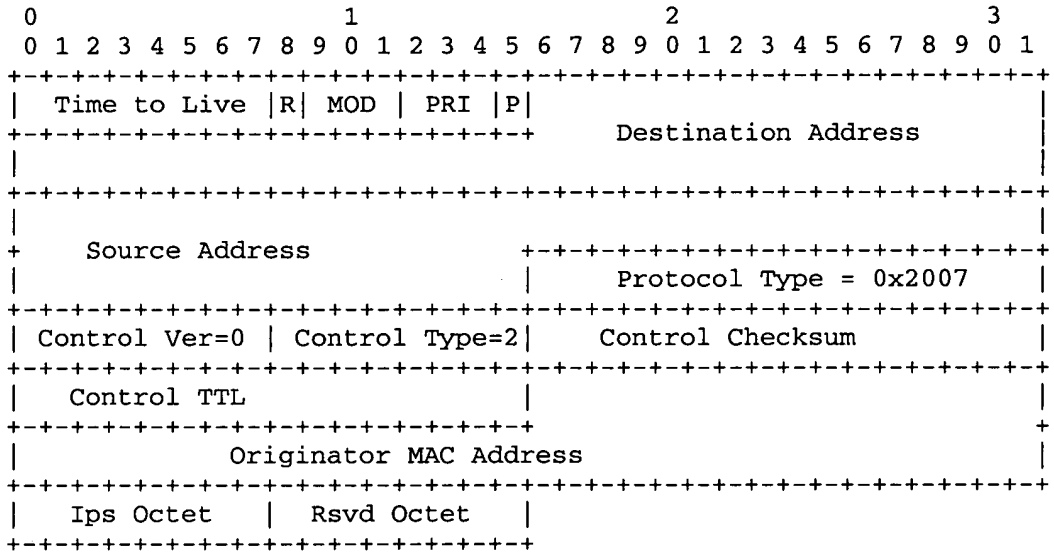
The topology information is not required for the IPS protection mechanism. This information can be used to calculate the number of nodes in the ring as well as to calculate hop distances to nodes to determine the shortest path to a node (since there are two counter-rotating rings).

The implementation of the topology discovery mechanism could be a periodic activity or on "a need to discover" basis. In the periodic implementation, each node generates the topology packet periodically and uses the cached topology map until it gets a new one. In the need to discover implementation, each node generates a topology discovery packet whenever they need one e.g., on first entering a ring or detecting a wrap.

4.7. Intelligent Protection Switching (IPS)

IPS is a method for automatically recovering from various ring failures and line degradation scenarios. The IPS packet format is outlined in Figure 14 below.

FIGURE 14. IPS Packet Format



The IPS specific fields are detailed below.

4.7.1. Originator MAC Address

This is the MAC address of the originator of the IPS message. It is not necessarily the same as the SRP Header Source Address as a node may be simply propagating an IPS message (see the section "SRP IPS Protocol Rules" Rule P.8 as an example).

4.7.2. IPS Octet

The IPS octet contains specific protection information. The format of the IPS octet is as follows:

FIGURE 15. IPS Octet Format:

Bits	Values (values not listed are reserved)
0-3	IPS Request Type 1101 - Forced Switch (FS) 1011 - Signal Fail (SF) 1000 - Signal Degrade (SD) 0110 - Manual Switch (MS) 0101 - Wait to Restore (WTR) 0000 - No Request (IDLE)
4	Path indicator 0 - short (S) 1 - long (L)
5-7	Status Code 010 - Protection Switch Completed - traffic Wrapped (W) 000 - Idle (I)

The currently defined request types with values, hierarchy and interpretation are as used in SONET BLSR [3], [4], except as noted.

4.8. Circulating packet detection (stripping)

Packets continue to circulate when transmitted packets fail to get stripped. Unicast packets are normally stripped by the destination station or by the source station if the destination station has failed. Multicast packets are only stripped by the source station. If both the source and destination stations drop out of the ring while a unicast packet is in flight, or if the source node drops out while its multicast packet is in flight, the packet will rotate around the ring continuously.

The solution to this problem is to have a TTL or Time To Live field in each packet that is set to at least twice the number of nodes in the ring. As each node forwards the packet, it decrements the TTL. If the TTL reaches zero it is stripped off of the ring.

The ring ID is used to qualify all stripping and receive decisions. This is necessary to handle the case where packets are being wrapped by some node in the ring. The sending node may see its packet on the reverse ring prior to reaching its destination so must not source strip it. The exception is if a node is in wrap. Logically, a node in wrap "sees" the packet on both rings. However the usual implementation is to receive the packet on one ring and to transmit it on the other ring. Therefore, a node that is in the wrap state ignores the ring ID when making stripping and receiving decisions.

A potential optimization would be to allow ring ID independent destination stripping of unicast packets. One problem with this is that packets may be delivered out of order during a transition to a wrap condition. For this reason, the ring ID should always be used as a qualifier for all strip and receive decisions.

5. Packet acceptance and stripping

A series of decisions based on the type of packet (mode), source and destination addresses are made on the MAC incoming packets. Packets can either be control or data packets. Control packets are stripped once the information is extracted. The source and destination addresses are checked in the case of data packets. The rules for reception and stripping are given below as well as in the flow chart in Figure 16.

1. Decrement TTL on receipt of a packet, discard if it gets to zero; do not forward.

2. Strip unicast packets at the destination station. Accept and strip "control" packets.

3. Do not process packets other than for TTL and forwarding if they have the "wrong" ring_id for the direction in which they are received unless the node is in wrap. If the node is in wrap then ignore the ring_id.

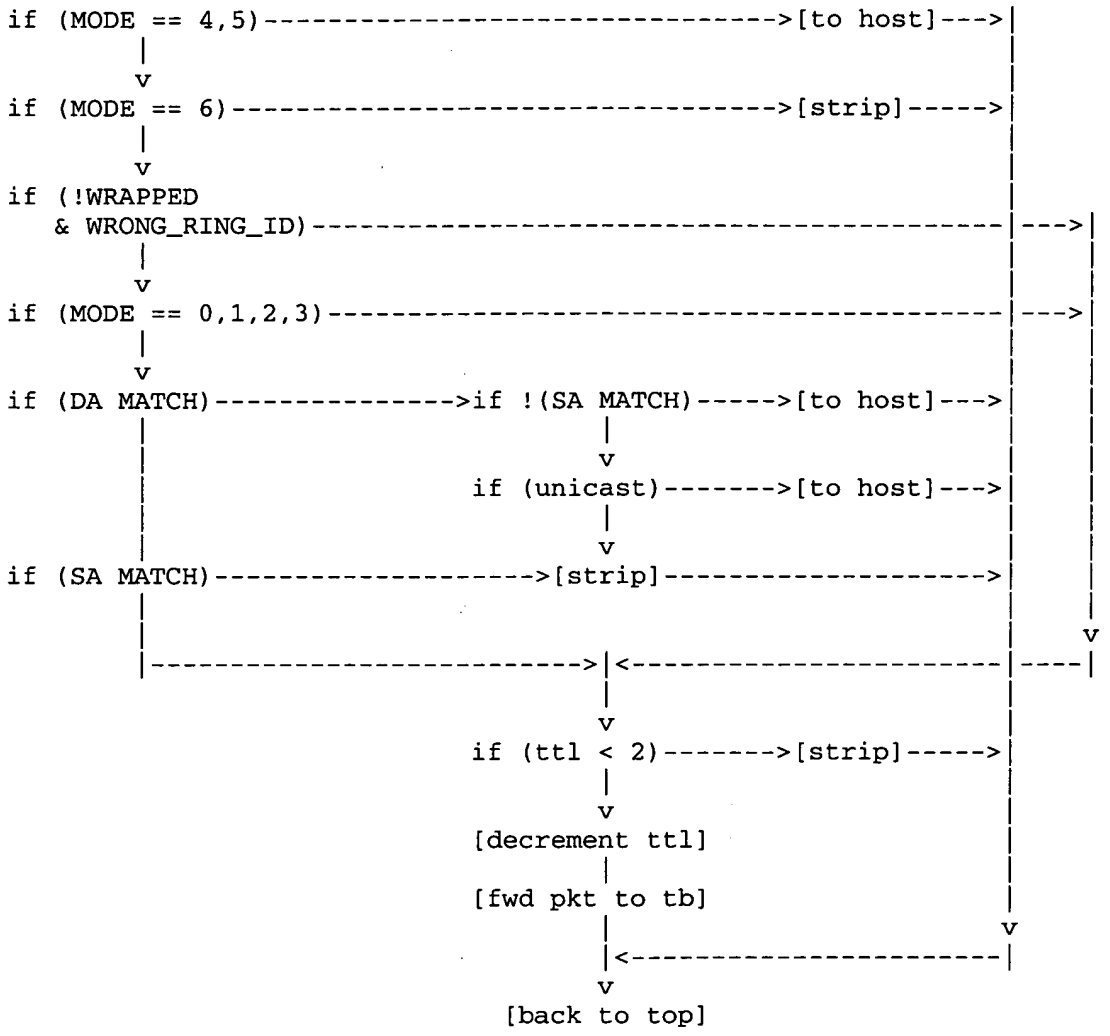
4. Do not process packets other than for TTL and forwarding if the mode is not supported by the node (e.g. reserved modes, or ATM cell mode for packet nodes).

5. Packets accepted by the host because of the destination address should be discarded at the upper level if there is CRC error.

6. Control messages are point to point between neighbors and should always be accepted and stripped.

7. Packets whose source address is that of the receiving station and whose ring_id matches should be stripped. If a node is in wrap then ignore the ring_id.

FIGURE 16. SRP Receive Flowchart (Packet node)



Notes: Host is responsible for discarding CRC errored packets. Conditionals (if statements) branch to the right if true and branch down if false.

5.1. Transmission and forwarding with priority

A node can transmit four types of packets:

1. High priority packets from the high priority transit buffer.

2. Low priority packets from the low priority transit buffer.

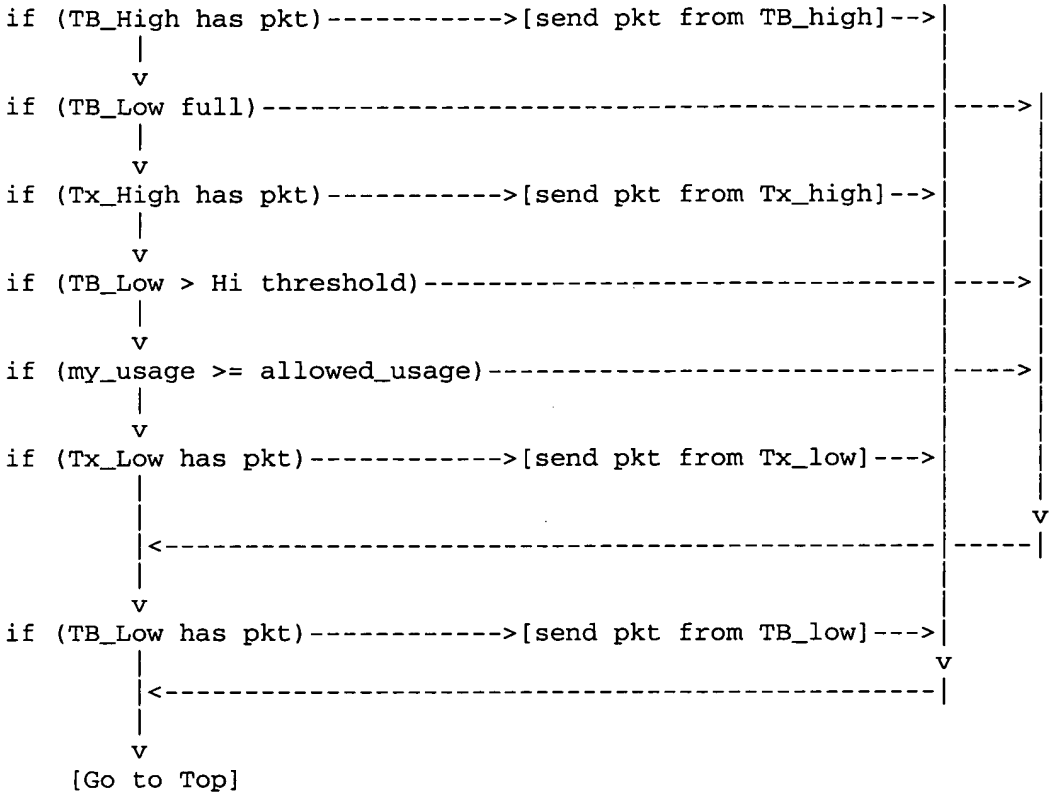
3. High priority packets from the host Tx high priority fifo.

4. Low priority packets from the host Tx low priority fifo.

High priority packets from the transit buffer are always sent first. High priority packets from the host are sent as long as the low priority transit buffer is not full. Low priority packets are sent as long as the transit buffer has not crossed the low priority threshold and the SRP-fa rules allow it (my_usage < allowed_usage). If nothing else can be sent, low priority packets from the low priority transit buffer are sent.

This decision tree is shown in Figure 17.

FIGURE 17. SRP transmit flowchart



Notes: Conditionals (if statements) branch to the right if true and branch down if false.

5.2. Wrapping of Data

Normally, transmitted data is sent on the same ring to the downstream neighbor. However, if a node is in the wrapped state, transmitted data is sent on the opposite ring to the upstream neighbor.

6. SRP-fa Rules Of Operation

The SRP-fa governs access to the ring. The SRP-fa only applies to low priority traffic. High priority traffic does not follow SRP-fa rules and may be transmitted at any time as long as there is sufficient transit buffer space.

The SRP-fa requires three counters which control the traffic forwarded and sourced on the SRP ring. The counters are my_usage (tracks the amount of traffic sourced on the ring), forward_rate (amount of traffic forwarded on to the ring from sources other than the host) and allowed_usage (the current maximum transmit usage for that node).

With no congestion all nodes build up allowed usage periodically. Each node can send up to max_usage. Max_usage is a per node parameter than limits the maximum amount of low priority traffic a node can send.

When a node sees congestion it starts to advertise its my_usage which has been low pass filtered (lp_my_usage).

Congestion is measured by the transit buffer depth crossing a congestion threshold.

A node that receives a non-null usage message (rcvd_usage) will set its allowed usage to the value advertised. However, if the source of the rcvd_usage is the same node that received it then the rcvd_usage shall be treated as a null value. When comparing the rcvd_usage source address the ring ID of the usage packet must match the receiver's ring ID in order to qualify as a valid compare. The exception is if the receive node is in the wrap state in which case the usage packet's ring ID is ignored.

Nodes that are not congested and that receive a non-null rcvd_usage generally propagate rcvd_usage to their upstream neighbor else propagate a null value of usage (all 1's). The exception is when an opportunity for local reuse is detected. Additional spatial reuse (local reuse) is achieved by comparing the forwarded rate (low pass filtered) to allow_usage. If the forwarded rate is less than the allowed usage, then a null value is propagated to the upstream neighbor.

Nodes that are congested propagate the smaller of lp_my_usage and rcvd_usage.

Convergence is dependent upon number of nodes and distance. Simulation has shown simulation convergence within 100 msec for rings of several hundred miles.

6.1. SRP-fa pseudo-code

A more precise definition of the fairness algorithm is shown below:

```
Variables:

lo_tb_depth     low priority transit buffer depth

my_usage        count of octets transmitted by host
lp_my_usage     my_usage run through a low pass filter
my_usage_ok     flag indicating that host is allowed to transmit

allow_usage     the fair amount each node is allowed to transmit

fwd_rate        count of octets forwarded from upstream
lp_fwd_rate     fwd_rate run through a low pass filter

congested       node cannot transmit host traffic without the TB buffer
                filling beyond its congestion threshold point.

rev_usage       the usage value passed along to the upstream neighbor

Constants:

MAX_ALLOWANCE = configurable value for max allowed usage for this node

DECAY_INTERVAL = 8000 octet times @ OC-12, 32,000 octet times @ OC-48

AGECOEFF = 4    // Aging coeff for my_usage and fwd_rate

LP_FWD  = 64    // Low pass filter for fwd_rate
LP_MU   = 512   // Low pass filter for my usage
LP_ALLOW = 64   // Low pass filter for allow usage auto increment

NULL_RCVD_INFO = All 1's in rcvd_usage field

TB_LO_THRESHOLD // TB depth at which no more lo-prio host traffic
                // can be sent

MAX_LRATE = AGECOEFF * DECAY_INTERVAL = 128,000 for OC-48, 32000 for
            OC-12
```

```
THESE ARE UPDATED EVERY CLOCK CYCLE:
====================================

my_usage        is incremented by 1 for every octet that is
                transmitted by the host (does not include data
                transmitted from the Transit Buffer).

fwd_rate        is incremented by 1 for every octet that enters the
                Transit Buffer

if ((my_usage < allow_usage) &&
        !((lo_tb_depth > 0) && (fwd_rate < my_usage)) &&
                (my_usage < MAX_ALLOWANCE))
        // true means OK to send host packets
        my_usage_ok = true;


UPDATED WHEN USAGE_PKT IS RECEIVED:
===================================

if (usage_pkt.SA == my_SA) &&
        [(usage_pkt.RI == my_RingID) || (node_state == wrapped)]
        rcvd_usage = NULL_RCVD_INFO;
else
        rcvd_usage = usage_pkt.usage;


THE FOLLOWING IS CALCULATED EVERY DECAY_INTERVAL:
=================================================

congested = (lo_tb_depth > TB_LO_THRESHOLD/2)

lp_my_usage = ((LP_MU-1) * lp_my_usage + my_usage) / LP_MU

my_usage is decremented by min(allow_usage/AGECOEFF, my_usage/AGECOEFF)

lp_fwd_rate = ((LP_FWD-1) * lp_fwd_rate + fwd_rate) / LP_FWD

fwd_rate is decremented by fwd_rate/AGECOEFF

(Note: lp values must be calculated prior to decrement of non-lp
values).

if (rcvd_usage != NULL_RCVD_INFO)
        allow_usage = rcvd_usage;
else
        allow_usage += (MAX_LRATE - allow_usage) / (LP_ALLOW);
```

```
if (congested)
      {
        if (lp_my_usage < rcvd_usage)
                rev_usage = lp_my_usage;
        else
                rev_usage =  rcvd_usage;
        }
else if ((rcvd_usage != NULL_RCVD_INFO) &&
         (lp_fwd_rate > allow_usage)
    rev_usage = rcvd_usage;
else
    rev_usage = NULL_RCVD_INFO

if (rev_usage > MAX_LRATE)
        rev_usage = NULL_RCVD_INFO;
```

6.2. Threshold settings

The low priority transit buffer (TB_LO_THRESHOLD) is currently sized to about 4.4 msec or 320 KB at OC12 rates. The TB_HI_THRESHOLD is set to about 870 usec higher than the TB_LO_THRESHOLD or at 458 KB at OC12 rates.

The high priority transit buffer needs to hold 2 to 3 MTUs or about 30KB.

7. SRP Synchronization

Each node operates in "free-run" mode. That is, the receive clock is derived from the incoming receive stream while the transmit clock is derived from a local oscillator. This eliminates the need for expensive clock synchronization as required in existing SONET networks. Differences in clock frequency are accommodated by inserting a small amount of idle bandwidth at each nodes output.

The clock source for the transmit clock shall be selected to deviate by no more than 20 ppm from the center frequency. The overall outgoing rate of the node shall be rate shaped to accommodate the worst case difference between receive and transmit clocks of adjacent nodes. This works as follows:

A transit buffer slip count (tb_cnt) keeps track of the amount of octets inserted into the TB minus the amount of octets transmitted and is a positive integer.

To account for a startup condition where a packet is being inserted into an empty TB and the node was otherwise idle the tb_cnt is reset if the transmit interface is idle. Idle is defined as no data being sent even though there is opportunity to send (i.e. the transmit interface is not prohibited from transmitting by the physical layer).

An interval counter defines the sample period over which rate shaping is performed. This number should be sufficiently large to get an accurate rate shaping.

A token_bucket counter implements the rate shaping and is a signed integer. We increment this counter by one of two fixed values called quantums each sample period. Quantum1 sets the rate at (Line_rate - Delta) where delta is the clock inaccuracy we want to accommodate.

Quantum2 sets the rate at (Line_rate + Delta). If at the beginning of a sample period, tb_cnt >= sync_threshold, then we set the rate to Quantum2. This will allow us to catch up and causes the TB slip count to eventually go < sync_threshold. If tb_cnt is < sync_threshold then we set the rate to Quantum1.

When the input rate and output rates are exactly equal, the tb_cnt will vary between sync_threshold > tb_cnt >= 0. This will vary for each implementation dependent upon the burst latencies of the design. The sync_threshold value should be set so that for equal transmit and receive clock rates, the transmit data rate is always Line_rate-Delta and will be implementation dependent.

The token_bucket is decremented each time data is transmitted. When token_bucket reaches a value <= 0, a halt_transmit flag is asserted which halts further transmission of data (halting occurs on a packet boundary of course which can cause token_bucket to become a negative number).

7.1. SRP Synchronization Examples

Assume an interval of 2^^18 or 262144 clock cycles. A Quantum1 value must be picked such that the data rate will = (LINE_RATE - DELTA). A Quantum2 value must be picked and used if the tb_cnt shows that the incoming rate is greater than the outgoing rate and is = (LINE_RATE + DELTA). Assume that the source of the incoming and outgoing rate clocks are +/- 100 ppm.

For an OC12c SPE rate of 600 Mbps and a system clock rate of 800 Mbps (16 bits @ 50 Mhz). The system clock rate is the rate at which the system transmits bytes to the framer (in most cases the framer transmit rate is asynchronous from the rate at which the system transfers data to the framer).

```
Quantum1/Interval * 800 Mbps = 600 Mbps(1 - Delta)
Quantum1 = Interval * (600/800) * (1 - Delta)
Quantum1 = Interval * (600/800) * (1 - 1e-4) = 196588

Quantum2/Interval * 800 Mbps = 600 Mbps(1 + Delta)
Quantum2 = Interval * (600/800) * (1 + Delta)
Quantum2 = Interval * (600/800) * (1 + 1e-4) = 196628
```

Note: The actual data rate for OC-12c is 599.04 Mbps.

8. IPS Protocol Description

An SRP ring is composed of two counter-rotating, single fiber rings. If an equipment or fiber facility failure is detected, traffic going towards and from the failure direction is wrapped (looped) back to go in the opposite direction on the other ring. The wrap around takes place on the nodes adjacent to the failure, under software control. This way the traffic is re-routed from the failed span.

Nodes communicate between themselves using IPS signaling on both inner and outer ring.

The IPS octet contains specific protection information. The format of the IPS octet is as follows:

FIGURE 18. IPS Octet format:

0-3 IPS Request Type

- 1101 - Forced Switch (FS)
- 1011 - Signal Fail (SF)
- 1000 - Signal Degrade (SD)
- 0110 - Manual Switch (MS)
- 0101 - Wait to Restore (WTR)
- 0000 - No Request (IDLE)

4 Path indicator

- 0 - short (S)
- 1 - long (L)

5-7 Status Code

- 010 - Protection Switch Completed -traffic Wrapped (W)
- 000 - Idle (I)

The IPS control messages are shown in this document as:

{REQUEST_TYPE, SOURCE_ADDRESS, WRAP_STATUS, PATH_INDICATOR}

8.1. The IPS Request Types

The following is a list of the request types, from the highest to the lowest priority. All requests are signaled using IPS control messages.

1. Forced Switch (FS - operator originated)

   This command performs the ring switch from the working channel to the protection, wrapping the traffic on the node at which the command is issued and at the adjacent node to which the command is destined. Used for example to add another node to the ring in a controlled fashion.

2. Signal Fail (SF - automatic)

   Protection caused by a media "hard failure" or SRP keep- alive failure. SONET examples of SF triggers are: Loss of Signal (LOS), Loss of Frame (LOF), Line Bit Error Rate (BER) above a preselected SF threshold, Line Alarm Indication Signal (AIS). Note that the SRP keep-alive failure provides end-to-end coverage and as a result SONET Path triggers are not necessary.

3. Signal Degrade (SD - automatic)

   Protection caused by a media "soft failure". SONET example of a SD is Line BER or Path BER above a preselected SD threshold.

4. Manual Switch (MS - operator originated)

   Like the FS, but of lower priority. Can be used for example to take down the WTR.

5. Wait to Restore (WTR - automatic)

   Entered after the working channel meets the restoration threshold after an SD or SF condition disappears. IPS waits WTR timeout before restoring traffic in order to prevent protection switch oscillations.

8.2. SRP IPS Protocol States

Each node in the IPS protocol is in one of the following states for each of the rings:

8.2.1. Idle

In this mode the node is ready to perform the protection switches and it sends to both neighboring nodes "idle" IPS messages, which include "self" in the source address field {IDLE, SELF, I, S}

8.2.2. Pass-through

Node participates in a protection switch by passing the wrapped traffic and long path signaling through itself. This state is entered based on received IPS messages. If a long path message with not null request is received and if the node does not strip the message (see Protocol Rules for stripping conditions) the node decrements the TTL and retransmits the message without modification. Sending of the Idle messages is stopped in the direction in which the message with not null request is forwarded.

8.2.3. Wrapped

Node participates in a protection switch with a wrap present. This state is entered based on a protection request issued locally or based on received IPS messages.

8.3. IPS Protocol Rules

8.3.1. SRP IPS Packet Transfer Mechanism

R T.1:

IPS packets are transferred in a store and forward mode between adjacent nodes (packets do not travel more than 1 hop between nodes at a time). Received packet (payload portion) is passed to software based on interrupts.

R T.2:

All IPS messages are sent to the neighboring nodes periodically on both inner and outer rings. The timeout period is configurable 1-600 sec (default 1 sec). It is desirable (but not required) that the timeout is automatically decreased by a factor of 10 for the short path protection requests.

8.3.2. SRP IPS Signaling and Wrapping Mechanism

R S.1:

IPS signaling is performed using IPS control packets as defined in Figure 14 "IPS Packet Format".

R S.2:

Node executing a local request signals the protection request on both short (across the failed span) and long (around the ring) paths after performing the wrap.

R S.3:

Node executing a short path protection request signals an idle request with wrapped status on the short (across the failed span) path and a protection request on the long (around the ring) path after performing the wrap.

R S.4:

A node which is neither executing a local request nor executing a short path request signals IDLE messages to its neighbors on the ring if there is no long path message passing through the node on that ring.

R S.5:

Protection IPS packets are never wrapped.

R S.6:

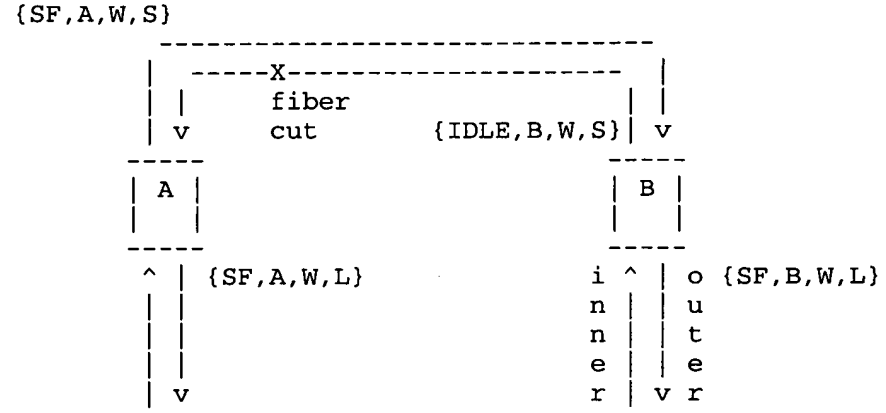
If the protocol calls for sending both short and long path requests on the same span (for example if a node has all fibers disconnected), only the short path request should be sent.

R S.7:

A node wraps and unwraps only on a local request or on a short path request. A node never wraps or unwraps as a result of a long path request. Long path requests are used only to maintain protection hierarchy. (Since the long path requests do not trigger protection, there is no need for destination addresses and no need for topology maps)

In Figure 19, Node A detects SF (local request/ self-detected request) on the span between Node A and Node B and starts sourcing {SF, A, W, S} on the outer ring and {SF, A, W, L} on the inner ring. Node B receives the protection request from Node A (short path request) and starts sourcing {IDLE, B, W, S} on the inner ring and {SF, B, W, L} on the outer ring.

FIGURE 19. SRP IPS Signaling



8.4. SRP IPS Protocol Rules

R P.1:

Protection Request Hierarchy is as follows (Highest priority to the lowest priority). In general a higher priority request preempts a lower priority request within the ring with exceptions noted as rules. The 4 bit values below correspond to the REQUEST_TYPE field in the IPS packet.

1101 - Forced Switch (FS)
1011 - Signal Fail (SF)
1000 - Signal Degrade (SD)
0110 - Manual Switch (MS)
0101 - Wait to Restore (WTR)
0000 - No Request (IDLE): Lowest priority

R P.2:

Requests >= SF can coexist.

R P.3:

Requests < SF can not coexist with other requests.

R P.4:

A node always honors the highest of {short path request, self detected request} if there is no higher long path message passing through the node.

R P.5:

When there are more requests of priority < SF, the first request to complete long path signaling will take priority.

R P.6:

A Node never forwards an IPS packet received by it which was originally generated by the node itself (it has the node's source address).

R P.7:

Nodes never forward packets with the PATH_INDICATOR set to SHORT.

R P.8:

When a node receives a long path request and the request is >= to the highest of {short path request, self detected request}, the node checks the message to determine if the message is coming from its neighbor on the short path. If that is the case then it does not enter pass-thru and it strips the message.

R P.9:

When a node receives a long path request, it strips (terminates) the request if it is a wrapped node with a request >= than that in the request; otherwise it passes it through and unwraps.

R P.10:

Each node keeps track of the addresses of the immediate neighbors (the neighbor node address is gleaned from the short path IPS messages).

R P.11:

When a wrapped node (which initially detected the failure) discovers disappearance of the failure, it enters WTR (user-configurable WTR time-period). WTR can be configured in the 10-600 sec range with a default value of 60 sec.

R P.12:

When a node is in WTR mode, and detects that the new neighbor (as identified from the received short path IPS message) is not the same as the old neighbor (stored at the time of wrap initiation), the node drops the WTR.

R P.13:

When a node is in WTR mode and long path request Source is not equal to the neighbor Id on the opposite side (as stored at the time of wrap initiation), the node drops the WTR.

R P.14:

When a node receives a local protection request of type SD or SF and it cannot be executed (according to protocol rules) it keeps the request pending. (The request can be kept pending outside of the protection protocol implementation).

R P.15:

If a local non-failure request (WTR, MS, FS) clears and if there are no other requests pending, the node enters idle state.

R P.16:

If there are two failures and two resulting WTR conditions on a single span, the second WTR to time out brings both the wraps down (after the WTR time expires a node does not unwrap automatically but waits till it receives idle messages from its neighbor on the previously failed span)

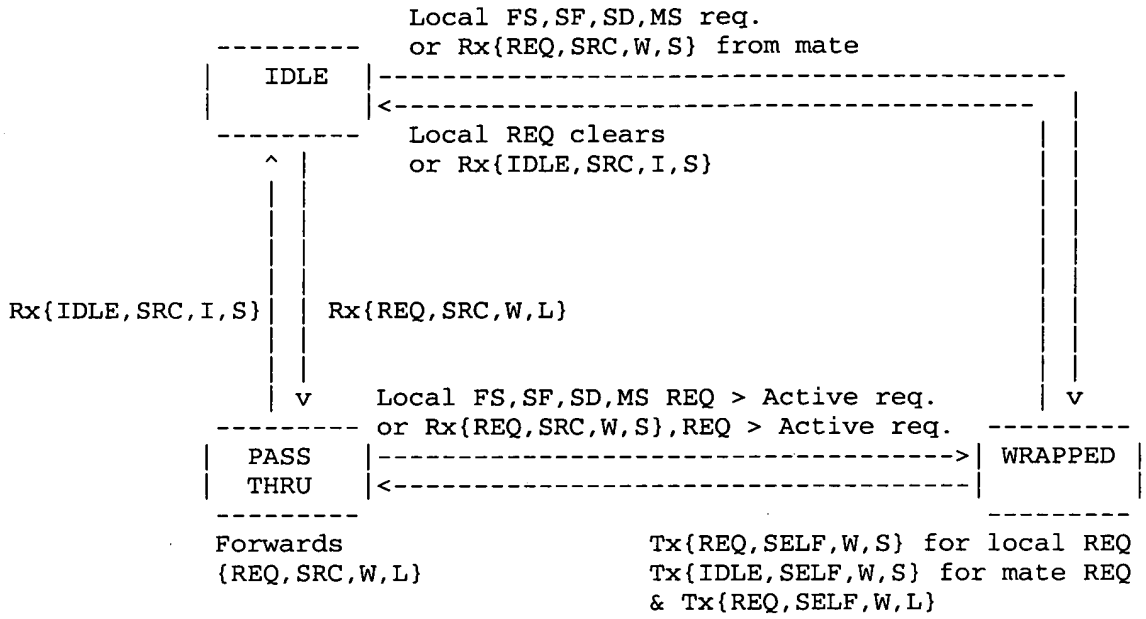
R P.17:

If a short path FS request is present on a given side and a SF/SD condition takes place on the same side, accept and process the SF/SD condition ignoring the FS. Without this rule a single ended wrap condition could take place. (Wrap on one end of a span only).

8.5. State Transitions

Figure 20 shows the simplified state transition diagram for the IPS protocol:

FIGURE 20. Simplified State Transitions Diagram



Legend: Mate = node on the other end of the affected span
REQ = {FS | SF | SD | MS}

8.6. Failure Examples

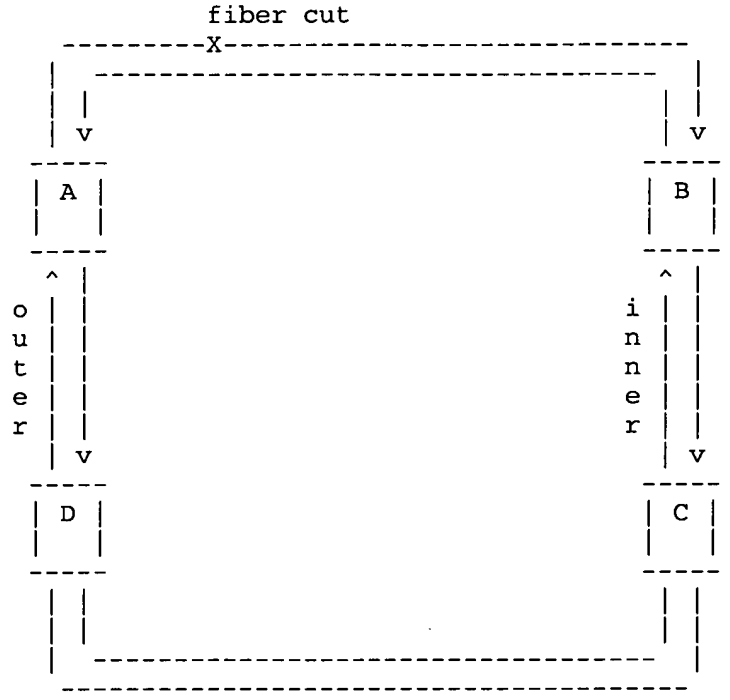
8.6.1. Signal Failure - Single Fiber Cut Scenario

Sample scenario in a ring of four nodes A, B, C and D, with unidirectional failure on a fiber from A to B, detected on B. Ring is in the Idle state (all nodes are Idle) prior to failure.

Signal Fail Scenario

1. Ring in Idle, all nodes transmit (Tx) {IDLE, SELF, I, S} on both rings (in both directions)

FIGURE 21. An SRP Ring with outer ring fiber cut



2. B detects SF on the outer ring, transitions to Wrapped state (performs a wrap), Tx towards A on the inner ring/short path: {SF, B, W, S} and on the outer ring/long path: Tx {SF, B, W, L}

3. Node A receives protection request on the short path, transitions to Wrapped state, Tx towards B on short path: {IDLE, A, W, S} (message does not go through due to the failure) and on the long path: Tx {SF, A, W, L}

4. As the nodes D and C receive a switch request, they enter a pass-through mode (in each direction) which mean they stop sourcing the Idle messages and start passing the messages between A an B

5. Steady state is reached

Signal Fail Clears

1. SF on B clears, B does not unwrap, sets WTR timer, Tx {WTR, B, W, S} on inner and Tx {WTR, B, W, L}

2. Node A receives WTR request on the short path, does not unwrap, Tx towards B on short path: {IDLE, A, W, S} (message does not go through due to the failure) and on the long path: Tx {WTR, A, W, L}

3. Nodes C and D relay long path messages without changing the IPS octet

4. Steady state is reached

5. WTR times out on B. B transitions to idle state (unwraps) Tx {IDLE, B, I, S} on both inner and outer rings

6. A receives Rx {IDLE, B, I, S} and transitions to Idle

7. As idle messages reach C and D the nodes enter the idle state (start sourcing the Idle messages)

8. Steady state it reached

8.6.2. Signal Failure - Bidirectional Fiber Cut Scenario

Sample scenario in a ring of four nodes A, B, C and D, with a bidirectional failure between A and B. Ring is in the Idle state (all nodes are Idle) prior to failure.

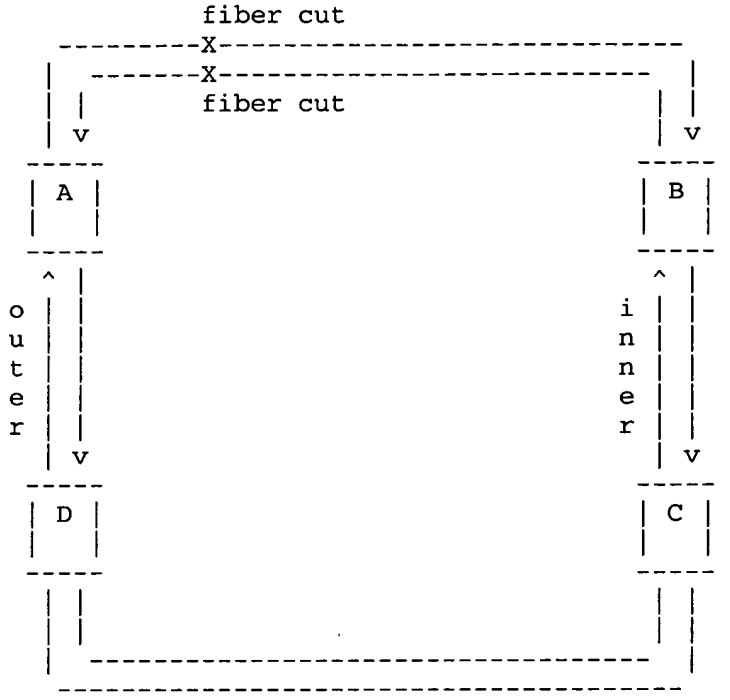
Signal Fail Scenario

1. Ring in Idle, all nodes transmit (Tx) {IDLE, SELF, I, S} on both rings (in both directions)

2. A detects SF on the outer ring, transitions to Wrapped state (performs a wrap), Tx towards B on the inner ring/short path: {SF, A, W, S} and on the outer ring/long path: Tx {SF, A, W, L}

3. B detects SF on the outer ring, transitions to Wrapped state (performs a wrap), Tx towards A on the inner ring/short path: {SF, B, W, S} and on the outer ring/long path: Tx {SF, B, W, L}

FIGURE 22. An SRP Ring with bidirectional fiber cut



4. As the nodes D and C receive a switch request, they enter a pass-through mode (in each direction) which mean they stop sourcing the Idle messages and start passing the messages between A an B

5. Steady state is reached

Signal Fail Clears

1. SF on A clears, A does not unwrap, sets WTR timer, Tx {WTR, A, W, S} towards B and Tx {WTR, A, W, L} on the long path

2. SF on B clears, B does not unwrap. Since it now has a short path WTR request present from A it acts upon this request. It keeps the wrap, Tx {IDLE, B, W, S} towards A and Tx {WTR, B, W, L} on the long path

3. Nodes C and D relay long path messages without changing the IPS octet

4. Steady state is reached

5. WTR times out on A. A enters the idle state (drops wraps) and starts transmitting idle in both rings

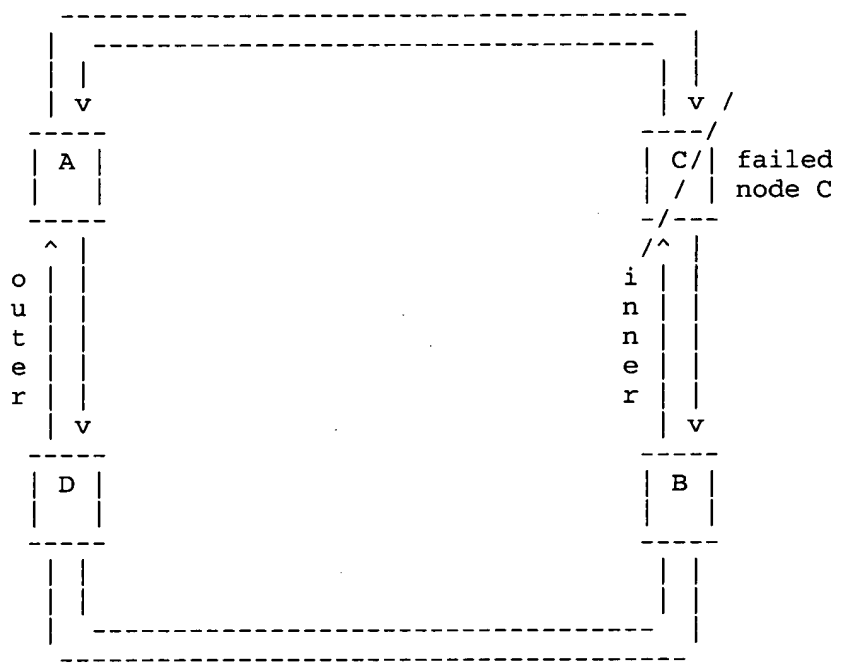
6. B sees idle request on short path and enters idle state

7. Remaining nodes in the ring enter the idle state

8. Steady state is reached

8.6.3. Failed Node Scenario

FIGURE 23. An SRP Ring with a failed node



Sample scenario in a ring where node C fails. Ring is in the Idle state (all nodes are Idle) prior to failure.

Node Failure (or fiber cuts on both sides of the node)

1. Ring in Idle, all nodes transmit (Tx) {IDLE, SELF, I, S} on both rings (in both directions)

2. Based on the source field of the idle messages, all nodes identify the neighbors and keep track of them

3. B detects SF on the outer ring, transitions to Wrapped state (performs a wrap), Tx towards C on the inner ring/short path: {SF, B, W, S} and on the outer ring/long path: Tx {SF, B, W, L}

4. A detects SF on the inner ring, transitions to Wrapped state (performs a wrap), Tx towards C on the outer ring/short path: {SF, A, W, S} and on the inner ring/long path: Tx {SF, A, W, L}

5. As the nodes on the long path between A and B receive a SF request, they enter a pass-through mode (in each direction), stop sourcing the Idle messages and start passing the messages between A an B

6. Steady state is reached

Failed Node and One Span Return to Service

Note: Practically the node will always return to service with one span coming after the other (with the time delta potentially close to 0). Here, a node is powered up with the fibers connected and fault free.

1. Node C and a span between A and C return to service (SF between A and C disappears)

2. Node C, not seeing any faults starts to source idle messages {IDLE, C, I, S} in both directions.

3. Fault disappears on A and A enters a WTR (briefly)

4. Node A receives idle message from node C. Because the long path protection request {SF, B, W, L} received over the long span is not originating from the short path neighbor (C), node A drops the WTR and enters a PassThrough state passing requests between C and B

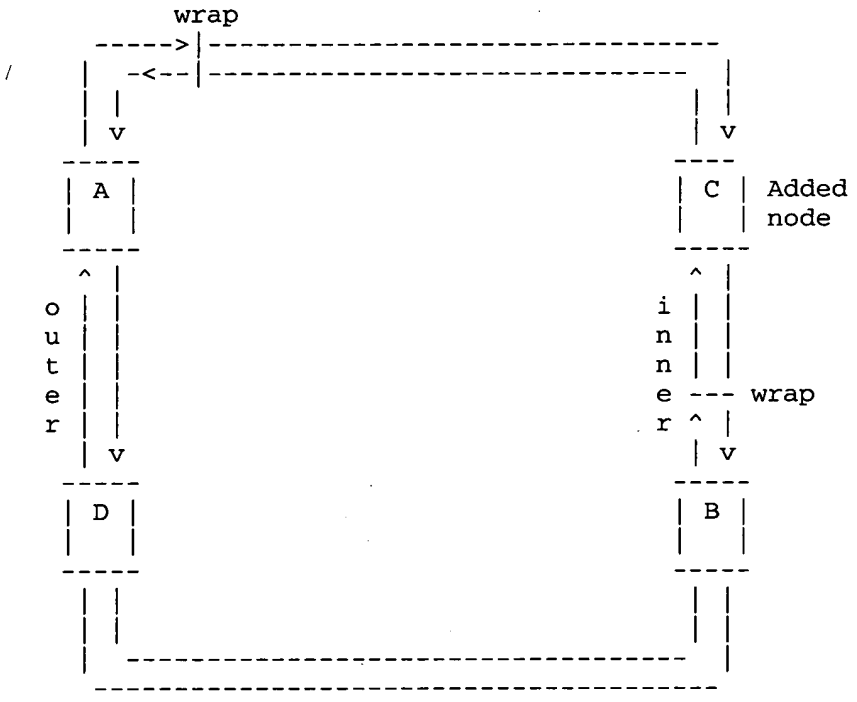
5. Steady state is reached

Second Span Returns to Service

The scenario is like the Bidirectional Fiber Cut fault clearing scenario.

8.6.4. Bidirectional Fiber Cut and Node Addition Scenarios

FIGURE 24. An SRP Ring with a failed node



Sample scenario in a ring where initially nodes A and B are connected. Subsequently fibers between the nodes A and B are disconnected and a new node C is inserted.

Bidirectional Fiber Cut

1. Ring in Idle, all nodes transmit (Tx) {IDLE, SELF, I, S} on both rings (in both directions)

2. Fibers are removed between nodes A and B

3. B detects SF on the outer ring, transitions to Wrapped state (performs a wrap), Tx towards A on the inner ring/short path: {SF, B, W, S} and on the outer ring/long path: Tx {SF, B, W, L}

4. A detects SF on the inner ring, transitions to Wrapped state (performs a wrap), Tx towards B on the inner ring/short path: {SF, A, W, S} and on the outer ring/long path: Tx {SF, A, W, L}

5. As the nodes on the long path between A and B receive a SF request, they enter a pass-through mode (in each direction), stop sourcing the Idle messages and start passing the messages between A an B

6. Steady state is reached

Node C is Powered Up and Fibers Between Nodes A and C are Reconnected

This scenario is identical to the returning a Failed Node to Service scenario.

Second Span Put Into Service

Nodes C and B are connected. The scenario is identical to Bidirectional Fiber Cut fault clearing scenario.

9. SRP over SONET/SDH

Although SRP is media independent it is worth noting how SRP is used with a layer 1 media type. SRP over SONET/SDH is the first media type perceived for SRP applications.

Flag delimiting on SONET/SDH uses the octet stuffing method defined for POS. The flags (0x7E) are packet delimiters required for SONET/SDH links but may not be necessary for SRP on other media types. End of a packet is delineated by the flag which could also be the same as the next packet's starting flag. If the flag (0x7E) or an escape character (0x7D) are present anywhere inside the packet, they have to be escaped by the escape character when used over SONET/SDH media.

SONET/SDH framing plus POS packet delimiting allows SRP to be used directly over fiber or through an optical network (including WDM equipment).

SRP may also connect to a SONET/SDH ring network via a tributary connection to a SONET/SDH ADM (Add Drop Multiplexor). The two SRP rings may be mapped into two STS-Nc connections. SONET/SDH networks typically provide fully redundant connections, so SRP mapped into two STS-Nc connections will have two levels of protection. The SONET/SDH network provides layer 1 protection, and SRP provides layer 2 protection. In this case it is recommended to hold off the SRP Signal Fail IPS triggers (which correspond to failures which can be

protected by SONET/SDH) for about 100 msec in order to allow the SONET/SDH network to protect. Only if a failure persists for over 100 msec (indicating SONET/SDH protection failure) should the IPS protection take place.

Since multiple protection levels over the same physical infrastructure are not very desirable, an alternate way of connecting SRP over a SONET/SDH network is configuring SONET/SDH without protection. Since the connection is unprotected at layer 1, SRP would be the sole protection mechanism.

Hybrid SRP rings may also be built where some parts of the ring traverse over a SONET/SDH network while other parts do not.

Connections to a SONET/SDH network would have to be synchronized to network timing by some means. This can be accomplished by locking the transmit connection to the frequency of the receive connection (called loop timing) or via an external synchronization technique.

Connections made via dark fiber or over a WDM optical network should utilize internal timing as clock synchronization is not necessary in this case.

10. Pass-thru mode

An optional mode of operation is pass-thru mode. In pass-thru mode, a node transparently forwards data. The node does not source packets, and does not modify any of the packets that it forwards. Data should continue to be sorted into high and low priority transit buffers with high priority transit buffers always emptied first. The node does not source any control packets (e.g. topology discovery or IPS) and basically looks like a signal regenerator with delay (caused by packets that happened to be in the transit buffer when the transition to pass-thru mode occurred).

A node can enter pass-thru mode because of an operator command or due to a error condition such as a software crash.

11. References

[1] ANSI X3T9 FDDI Specification

[2] IEEE 802.5 Token Ring Specification

[3] Bellcore GR-1230, Issue 4, Dec. 1998, "SONET Bidirectional Line-Switched Ring Equipment Generic Criteria".

[4] ANSI T1.105.01-1998 "Synchronous Optical Network (SONET) Automatic Protection Switching"

[5] Malis, A. and W. Simpson, "PPP over SONET/SDH", RFC 2615, June 1999.

[6] Simpson, W., "PPP in HDLC-like Framing", STD 51, RFC 1662, July 1994.

12. Security Considerations

As in any shared media, packets that traverse a node are available to that node if that node is misconfigured or maliciously configured. Additionally, it is possible for a node to not only inspect packets meant for another node but to also prevent the intended node from receiving the packets due to the destination stripping scheme used to obtain spatial reuse. Topology discovery should be used to detect duplicate MAC addresses.

13. IPR Notice

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15. Authors' Addresses

Comments should be sent to the authors at the following addresses:

David Tsiang
Cisco Systems
170 W. Tasman Drive
San Jose, CA 95134

Phone: (408) 526-8216
EMail: tsiang@cisco.com

George Suwala
Cisco Systems
170 W. Tasman Drive
San Jose, CA 95134

Phone: (408) 525-8674
EMail: gsuwala@cisco.com

16. Full Copyright Statement

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